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Quarterly Highlights of Sandia's Photovoltaics Program

Sandia National Laboratories

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TOPICS THIS QUARTER

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The following is the first of a number of comprehensive analyses of installed photovoltaic-hybrid power systems being performed by the Photovoltaic Systems Assistance Center. Preliminary results were presented by Andy Rosenthal at the 1997 Photovoltaic Performance and Reliability Workshop in Las Cruces, NM, and this article presents the completed evaluation. The analysis of two more systems has been completed over recent months and the results will be presented at the next Photovotaic Performance and Reliability Workshop scheduled for November 1998, which will be hosted by the Florida Solar Energy Center in Cocoa Beach, Florida (see page 12 for details).

DANGLING ROPE MARINA: A PHOTOVOLTAIC-HYBRID POWER SYSTEM

The National Park Service has operated a large photovoltaic (photovoltaic) hybrid power system at the Dangling Rope Marina since August 1996. This report summarizes the first year performance, reliability, and economics of the system at this remote installation on the north shore of Lake Powell in Utah. It also compares these results with those projected in the 1992 State of Utah Natural Resources Division of Energy document that first proposed installation of the hybrid system.

Over its first year, the hybrid system has been reliable and efficient with the photovoltaic array producing over one third of all site energy. Compared with a full-time generator, it requires less fuel, produces fewer emissions, and requires less regular maintenance.

Dangling Rope Marina, Lake Powell, Utah. *Located forty miles from the nearest services, this marina serves thousands of boaters each year on one of America's most popular lakes. The photovoltaic hybrid generating system installed in 1996 requires half the fuel and barge deliveries, produces fewer emissions, and needs less maintenance than the old diesel-fueled system.*

Some other favorable findings from the first year of hybrid system operation are:

- Hybrid system availability was high (99.6%).
- Risk of a diesel fuel spill to Glen Canyon National Recreation Area and Lake Powell was eliminated.
- Annual fuel use was reduced from 62,123 gallons (diesel) to 54,442 gallons (propane). Fuel savings are greater than the numbers indicate. By volume, propane contains only 2/3 the heat energy of diesel. Thus, the propane consumed is equivalent to about 36,000 gallons of diesel - energy savings of 42% compared to 1991 levels.
- Levelized cost of operating the hybrid (fuel, maintenance, and replacement costs) are $77k less per annum than for a diesel-only system.

There are also some unfavorable findings:

- The 1996/97 site electrical load was 22% greater than anticipated in the 1992 analysis.
- The large site load resulted in greater fuel use and operating costs than anticipated by the 1992 analysis.
- The system cost of installation was high: $1.35M.

This report is presented in seven sections. Section One describes the hybrid system and its components. Section Two summarizes the performance data for the year including: site electrical load; photovoltaic production; genset production, run-time, and fuel use. Section Three documents system downtime, maintenance actions, and their costs. Section Four presents the 1996/97 energy data and reviews the system energy data simulated in 1992. Reasons for differences between predicted and measured performance are given. Section Five presents an economic analysis of the installed hybrid power system including 20-Life Cycle Cost. Comparison is made between these costs and 1992 cost projections. Section Six presents a discussion of the value of fuel shifting, and Section Seven summarizes all conclusions.

Section 1.
Introduction

The original power system at Dangling Rope consisted of three diesel generators: two Caterpillar 310-kW prime power generators; and one Cummins 230-kW backup generator.

Construction of the photovoltaic hybrid at Dangling Rope Marina began in spring of 1996 by Applied Power Corporation (Lacey, WA). It was completed in August of that year. The system consists of a photovoltaic array, a battery bank, an inverter/rectifier, and two propane-fueled generators.

Figure 1. Photovoltaic Array. *The array consists of 384 modules arranged in seven parallel strings with a nominal operating voltage of 396 Vdc. Sandia produced simulations that showed favorable economics for this configuration.*

The photovoltaic array is shown in Figure 1. The array consists of 384 ASE 300-DG/50 modules. The nominal array dc rating is 115 kW. The array is configured as seven parallel strings with a nominal operating voltage of 396 Vdc. Array size and battery capacity were chosen after simulations by Sandia National Laboratories indicated favorable economics for this configuration.

The inverter/rectifier, shown in Figure 2, was built by Kenetech Windpower (now Trace Technologies). It uses the model HY-250 Power Processing Unit. In the inverting mode it produces 480 Vac, 3 phase 60 Hz power with a continuous rating of 250 kVA. Inverter size was selected to be able to supply the peak site load (measured at 125 kW ac) while also charging batteries. The 250 kVA size also accommodates moderate future load growth.

The battery bank is shown in Figure 3. The battery bank consists of 792 C&D model 6-C125-25 cells arranged in 40 steel trays. The bank is configured into four parallel strings with a total capacity of 2.4 MWh at the nominal 396 Vdc operating voltage.

There are two Caterpillar model 3408 propane-fueled generators, shown in in photo on page 6. Each is rated at 250 kVA, 3 phase, 480 Vac. Though the inverter supports ramping of the load to the generator, generators were sized to support worst-case block-loading conditions which could occur during inverter failure or black-out.

In addition to the subsystems mentioned, the entire hybrid system is monitored by a dedicated data acquisition system (DAS) designed and installed by the Southwest Technology Development Institute. The DAS monitors and records system performance and weather data. It can also exercise supervisory and control functions. The schematic on page 9 presents a one-line diagram of the photovoltaic hybrid system and indicates the parameters monitored by the DAS.

The loads at Dangling Rope are divided between the park and concessionaire residences and the concession store and fuel dock. When the hybrid was installed, steps were taken to reduce the overall electrical load. Compact fluorescent lamps replaced existing incandescent lamps in the residences. Also, several existing electrical appliances were replaced with propane-fueled units. These included: 6 furnaces, 12 stoves, 12 water heaters, and 6 clothes dryers.

Section 2.

Performance and Production Data

This section presents a summary of some of the performance data recorded by the on-site DAS during the first year of operation of the Dangling Rope photovoltaic hybrid power system.

Figure 4 (see page 5) presents the monthly totals for the site electrical load and the energy produced by the generators and photovoltaic. Over the year, the site electrical load was 438.3 MWh. The ratio of largest to smallest monthly loads was about 2:1 with the largest loads occurring during mid-summer months and the

Figure 2. Inverter/Rectifier. *In the inverter mode, this unit produces 480 Vac, 3 phase 60 Hz power with a continuous rating of 250 kVA. The inverter was sized to accommodate modest future growth.*

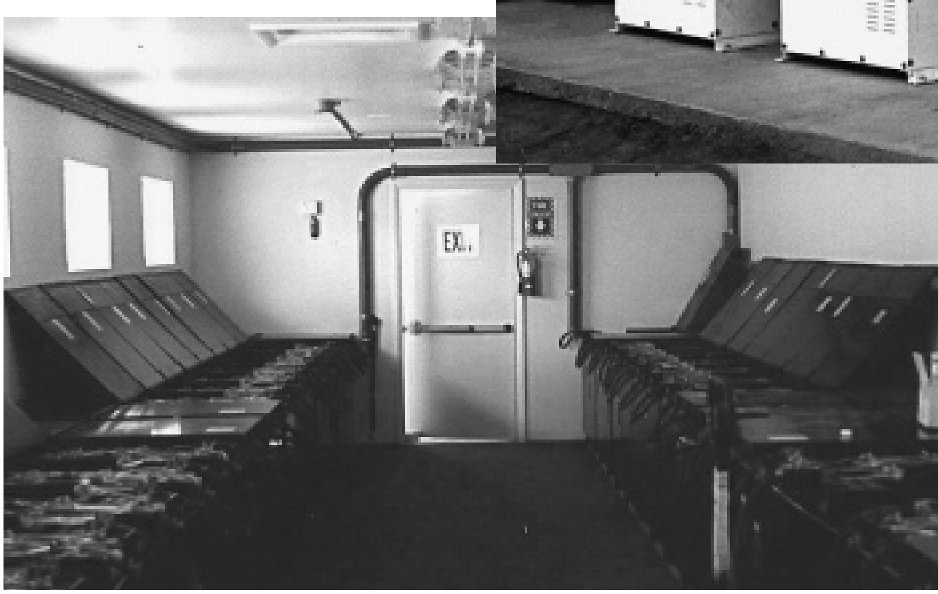


Figure 3. Battery Bank. *Arranged in 40 steel trays are 792 cells configured in four parallel strings with a total capacity of 2.4 MWh at the nominal 396 Vdc operating range.*

smallest loads during the late-winter months. Overall, the two generators produced 345.4 MWh of electricity and the photovoltaic array produced 180.5 MWh (dc). Thus, of the total generation on-site of 525.9 MWh, more than one-third was produced by the photovoltaic array. Since site load accounted for 438.3 MWh, system energy losses were 87.6 MWh, or 16.6% of all generation.

Approximately 58,808 gallons of fuel were delivered to the site during the year, of which 54,442 gallons were used by the generators. The balance was used by propane space heaters, stoves, and other appliances. Generator electrical production averaged 6.3 kWh/gal of propane consumed. Total generator run-time (split between two generators) was 2516 hours.

Table 1
Dangling Rope Marina Photovoltaic Hybrid Power System
Year 1 Downtime and Maintenance Summary

System Downtime (hrs)	Labor (Man-hrs)	Date	Description
00	04	09/01/96	Battery String 2 problems. String removed.
07	02	09/20/96	UPS fuse blew.
09	02	09/23/96	UPS fuse blew.
01	01	10/10/96	UPS fuse blew.
00	24	10/10/96	Battery String 2 reinstalled, equalized.
01	08	11/05/96	Generator failed to start, system in blackout.
01	01	11/05/96	Inverter door opened.
00	20	11/12/96	Unscheduled generator maintenance.
00	27	12/04/96	Battery watering and equalization.
12	8	12/31/96	UPS fuse blew.
00	30	01/08/97	Repair photovoltaic contactor.
02	10	01/14/97	Generator overspeed fault.
01	05	01/15/97	Generator overspeed fault.
00	10	02/05/97	Generator mechanic servicing both generators.
00	6	03/08/97	Generator low oil fault.
00	48	03/17/97	Scheduled battery maintenance.
02	08	05/20/97	Battery failure during equalization. String 2 down.
00	04	05/24/97	Remove failed batteries.
00	04	06/26/97	Equalize and re-water batteries.
00	00	07/28/97	DC contactor failure. System running on generator.
00	30	08/01/97	Replace failed dc contactor.

Section 3.
Downtime and Maintenance

The DAS provides templates for recording component failures and maintenance action reports. Table 1 presents a summary of the entries made via the DAS maintenance recording screens.

The entries in Table 1 include regular maintenance actions for the batteries (e.g. watering) but not the regular maintenance actions taken on the generators (e.g. oil changes). Records of these actions were not available. Regular maintenance, in keeping with the schedule shown in Appendix A, has been followed.

Hybrid power systems incorporate redundant generation sources so the system often remains on-line producing power during component or subsystem failures. For example, in July, when a dc contactor failure prevented the inverter from connecting to the batteries, the site was supplied by generator power. Thus, during that 3-day period, system downtime was 0 hours.

There were 36 hours of system downtime during the year. System power was available 99.6% of the time. Scheduled maintenance accounted for 103 man-hours of labor, unscheduled accounted for 149 man-hours. The few major problems experienced during the year were distributed between all three major subsystems: inverter, generators, battery.

Initial problems with the inverter's uninterruptible power supply have been resolved and have not recurred. Both generators required unscheduled maintenance to repair a recurring overspeed problem, but this condition has also been eliminated. The batteries suffered problems initially, with one leaking cell having to be replaced in the first month of operation. A second problem occurred in the ninth month when excessive pressure blew off 20 battery caps and 11 battery cells deformed during an equalization cycle. Analysis concluded that this was the result of a manufacturing defect and the deformed cells were replaced under warranty. Lastly, a failed dc contactor isolated the batteries from the inverter for several days in the tenth month, necessitating that site power be provided by the generators. This was also replaced.

Section 4.

Energy Requirements of the 1996/97 System and Comparison with 1992 Estimates

The report that first identified Dangling Rope Marina as a candidate for a photovoltaic hybrid power system was Lake Powell Solar Energy Project, Dangling Rope Marina prepared by Britt Reed of the State of Utah Natural Resources Division of Energy in December 1992 (henceforth referred to as the Utah report). This report assessed the site electrical load and conducted a thorough examination of the economics of augmenting the existing diesel generators with either batteries alone or batteries and a 105 kW photovoltaic array. Sandia National Laboratories Photovoltaic Design Assistance Center provided simulation analyses for these proposed systems. Based on these simulations and the economics of each, the report recommended the installation of the photovoltaic hybrid option.

This section compares the first year (1996/97) performance of Dangling Rope photovoltaic hybrid power system with the performance projected for the system in the 1992 Utah report. There are two major reasons for the differences observed between the actual and predicted performance of the system:

- The installed system differs from the specifications of the system recommended in the Utah report.
- The 1996/97 annual site load was 22% greater than anticipated in the Utah report.

The Utah report presented measured monthly site electrical load values for the years 1990 through 1992. Based on these measurements, the typical annual site load was determined to be 360-374 MWh. The monthly loads had peaks in the summer (air conditioning loads) and in the winter (space heating loads). Annual diesel fuel consumption was 62,123 gallons by the generators, which ran 8760 hours per year.

The Utah report recommended replacement of electric space and water heaters with propane units and installation of energy efficient lighting and other appliances. As a result of this conservation and fuel shifting, the anticipated site load would be reduced, especially the winter peaks. Figure 5 shows the measured 1991/92 monthly loads, the loads expected for the proposed hybrid (92 Solar Model), and the recorded 1996/97 monthly loads.

Conservation and fuel shifting effectively reduced the 1996/97 winter peaks to near predicted levels. However, summer loads were far larger than predicted. Total site electrical load was 438 MWh compared with an anticipated 1992 load of 360 mWh. It is worth noting that NPS records for 1995, prior to fuel shifting and other conservation measures, showed the annual site electrical load was 490 MWh.

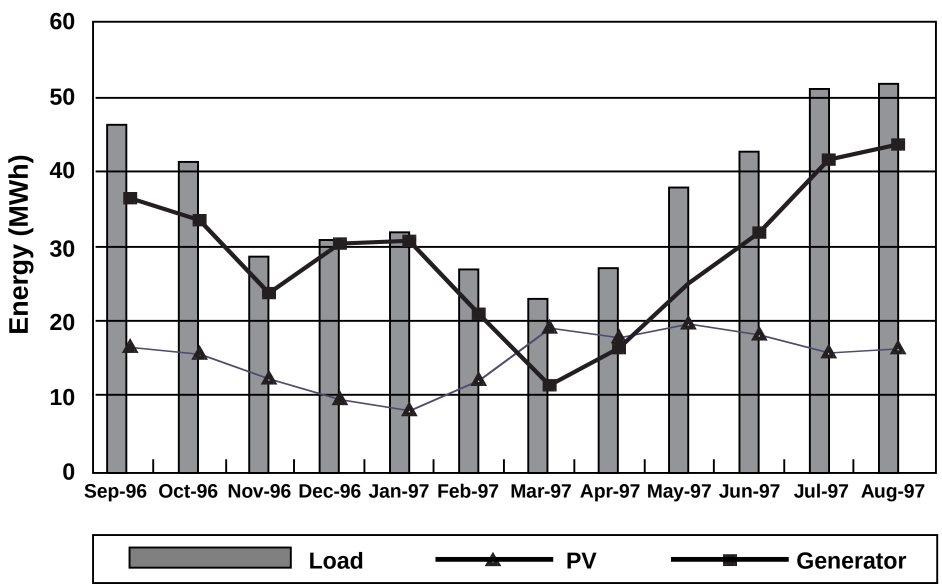


***Figure 4. Dangling Rope Photovoltaic Hybrid Power System.** Monthly Electrical Load and Generation by Photovoltaic Array and Propane Generators.*

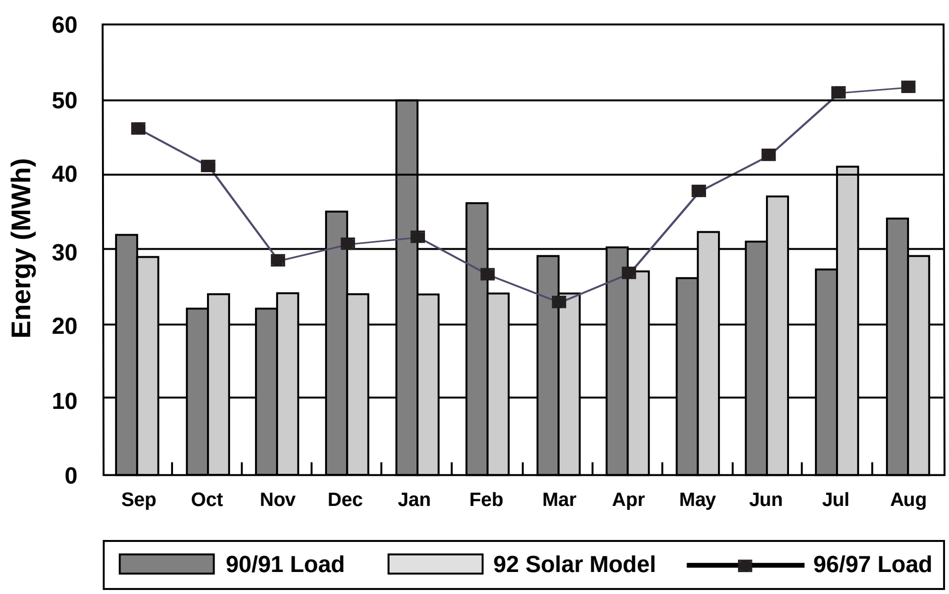
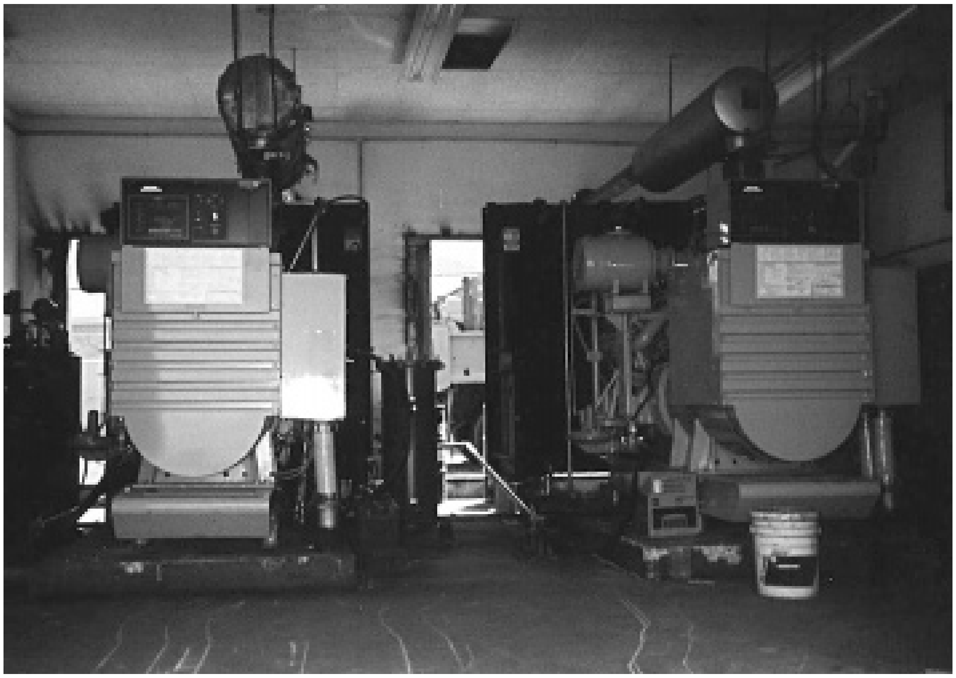


***Figure 5. Dangling Rope Photovoltaic Hybrid Power System.** 90/91 Site Load, Load for 92 Hybrid Model, and 96/97 Site Load.*



Propane-fueled Generators. *These generators were sized to support a worst-case scenario of block-loading conditions which would occur during inverter failure or blackout.*

The Utah report proposed retaining the existing diesel generators and using these to meet the site load and charge batteries, as needed. Coupled with the modified load, the required annual generator production was expected to be 260 MWh and 1456 hours of run time at an average generator loading of 76% of rated power. Annual fuel consumption was projected to be 22,600 gallons of diesel fuel.

The large 1996/97 site load necessitated more generator run time than predicted. In addition, the lower energy value of propane (by volume) meant greater fuel consumption than planned. Actual generator production was 345 MWh of energy from 2516 hours of run time. Total propane consumption by the generators was 54,442 gallons.

It should not be overlooked that though this is more run time and fuel than expected, this still represents considerable savings in fuel and engine run time when compared with full-time generator operation.

Section 5.

Economics of the 1996/97 System and Comparison with 1992 Estimates

This section presents the 20-year life cycle cost (LCC) of the Dangling Rope hybrid power system and compares it with projections made in the Utah report. The first step is to review the economic analysis originally presented in the Utah report.

Figure 10 (p. 22) of the Utah report showed the 20-year cost savings associated with the installation of the hybrid: $1.4M when a nominal (includes general inflation) discount rate of 6% is used; and $2.7M when the nominal discount rate is 0%. Though not stated, these numbers are true only if the initial cost of the hybrid is excluded from the LCC analysis. That is, the analysis is performed as though the cost of hybrid purchase is a sunk cost and not part of the study.

The appendix of the Utah report presents the complete LCC of each system. There, it shows that the present values for the two power systems are nearly identical: $2.54M for the existing system and $2.50M for the hybrid.

Elsewhere, the Utah report states that one benefit of the proposed 105 kW hybrid system is that it will:

- reduce operating costs at Dangling Rope Marina approximately $100,000 per year (p. 28).

The $100,000 figure was obtained by taking the 1990/91 diesel operating costs, $143,370, and subtracting the projected $42,664 annual operating cost for the hybrid. However, these numbers are not consistent. The larger number is rightly called an OM&R value (Operations, Maintenance and Replacement) and includes a contribution for engine replacement ($13,000 per year, new engines every 5 years). The smaller number was calculated without including the cost of battery replacement ($300,000 in year 10). Neither of these figures were discounted over the life of the project for an accurate annualized cost. Recalculating the original numbers in the 1992 model, the projected cost of operating the hybrid is found to be about $85,000 per year less than the diesel.

Lastly, costs in the Utah report were adjusted using tables that provided separate annual inflation rates for fuel, equipment, and labor. A nominal discount rate of 6% was adopted. This approach will not be reproduced here. In all cases, LCC will be calculated using constant dollars, the DOE real discount rate for 1996 (4.1%), and the DOE Energy Information Administration price escalation rates for each fuel type involved (diesel or propane). This method complies with the life cycle costing rules and procedures followed by all federal agencies for projects related to energy or water. Appendix C presents a comparison of economic results when discount rates of 6% and 8% are adopted.

For this report, five LCC cases are calculated. The descriptions of each are presented in Table 2.

The first two cases reevaluate the economics of the two systems as they were modeled in 1992 with two differences: the Base92 case includes initial cost for new generators in year 0 ; Hybrid92 uses $1.38/gal instead of $0.60 used in 1992. The latter three cases evaluate cost options for site power using the measured 1996/97 site electrical load. Cases 3 and 4 calculate LCC for full-time diesel and propane generator systems, respectively. Case 5 evaluates the economics of the actual photovoltaic hybrid system.

Table 3 presents the 20-year LCC comparison of the two 1992 cases. Including initial costs, the present value of the 1992 hybrid (1992 dollars) was $208k greater than the diesel-only base case.

Table 4 presents the LCC comparison of the three 1996 cases. Appendix B contains the complete details and specifications on which these LCC were based.

When all initial costs are included, the diesel-only (Base96-d) system has the lowest present value of the 1996 cases.

Comparing the two propane-based alternatives, Base96-p and Hybrid-96, we can calculate the payback year in which total cost of the hybrid system becomes less than the generator-only alternative. In this case, discounted payback occurs in year 19 of operation. In addition, at the end of its 20-year life, the hybrid will have saved over one million gallons of propane that would have been required by the propane generator-only alternative.

In broad terms, the hybrid saves over half the fuel and requires about one-third of the maintenance needed by either of the alternative (propane or diesel) systems. Thus, annual fuel and maintenance costs and maintenance man-hours are far less. Table 5 presents the annualized cost for the three 1996 systems. These are calculated twice: once with initial costs included and once with initial costs treated as sunk costs (excluded).

Once again, when initial costs are included, the cost of electricity per kWh for the three systems are comparable. And, once again, when initial costs are excluded, the lower fuel

Table 2
Dangling Rope Marina Photovoltaic Hybrid Power System
Five 20-Year LCC Cases

Case Number	Case Name	Description
1	Base92	360 MWh annual load; full-time diesel generator system.
2	Hybrid92	360 MWh annual load; 105 kW photovoltaic hybrid power system
3	Base96-d	438 MWh annual load; full-time diesel power system.
4	Base96-p	438 MWh annual load; full-time propane generator system.
5	Hybrid96	438 MWh annual load; 115 kW photovoltaic hybrid power system (the installed system).

Table 3
Dangling Rope Marina 20 Year Life Cycle Cost Comparison
Two 1992 System Alternatives

	Base92	Hybrid92
Initial Investment		
Capital Costs as of Service Date	$86,868	$1,449,810
Future Costs		
Annual and Non-Annual Recurring Costs	$350,593	$113,037
Energy-Related Costs	$1,627,459	$673,567
Capital Replacements	$164,039	$200,731
Net Present Value	$2,228,959	$2,437,145

Table 4
Dangling Rope Marina 20 Year Life Cycle Cost Comparison
Three 1996 System Alternatives

	Base96-d	base96-p	Hybrid96
Initial Investment			
Capital Costs as of Service Date	$86,868	$86,868	$1,300,000
Future Costs			
Annual and Non - Annual Recurring Costs	$393,699	$393,699	$190,484
Energy-Related Costs	$2,066,865	$2,336,602	$1,198,305
Capital Replacements	$164,039	$164,039	$200,731
Net Present Value	$2,711,472	$2,981,209	$2,889,520

and maintenance requirements of the hybrid make it much cheaper to operate. In this case, the cost per kWh drops by about 50%.

The LCC totals presented in Table 4 do not include emissions costs in the analysis. Dollar penalties for environmental emissions can be either included or excluded based on system purchaser, municipality or state regulations, or other conditions.

Table 5

Dangling Rope Marina Annualized Cost of Operation and Cost per kWh Computed With and Without Initial Costs Three 1996 System Alternatives

	Base96-d	Base96-p	Hybrid96
Annual Value (including initial costs)			
Annualized cost of buying and and operating	$201,286	$221,309	$214,503
Cost/kWh			
Annual load 438 MWh	0.46	$0.51	$0.49
Annual Value (excluding initial costs)			
Annualized cost of operation only	$194,837	$214,860	$117,998
Cost/kWh			
Annual load 438 MWh	$0.44	$0.49	$0.27

Table 6

Dangling Rope Marina Annual Emissions Costs Estimates Three 1996 System Alternatives

	Base96-d	Base96-p	Hybrid96
Emission			
CO2 tons/year $/yr	871 $12,194	724 $8,688	371 $5,194
SO2 lbs/year $/yr	2534 $1901	7 $5	4 $3
Nox lbs/yr $/yr	1555 $5,287	2196 $7,466	1126 $3,828
Total Annual Cost	$19,382	$16,159	$9,025

The Dangling Rope Marina is in the Glen Canyon National Recreation Area and National Park Service guidelines apply. These guidelines require that the following emissions costs be applied to energy projects within park facilities: $14/ton for CO2; $0.75/lb for SO2; $3.40/lb for NOx. Table 6 shows the annual costs associated with the estimated emissions for the three 1996 system alternatives.

Including these annually recurring emissions costs, net present values for the Base96-d, Base96-p, and Hybrid96 cases become $2.97M, $3.20M, and $3.01M, respectively.

Section 6.

Fuel Shifting

One aspect of the hybrid system implementation, the conversion of 36 existing electrical appliances to propane (fuel shifting), was a practical idea that will pay for itself in the first few years of operation. Propane-fueled water heaters, space heaters, and dryers capture between 50% and 80% of the fuel's heat energy for useful work. In contrast, the generators converted propane at a rate of approximately 6.3 kWh/gallon. While this is efficient operation for a generator, it represents only 23% conversion efficiency of the fuel's heat energy to electricity.

Thus, to meet the same load, the electrical appliances required from two to four times the fuel of the propane appliance replacements. At Dangling Rope, propane appliances used about 4366 gallons of fuel in 1996/97. In round numbers, therefore, the avoided fuel cost represents between $6k and $12k per year. The estimated cost for the installed propane appliances is $22k. Based on avoided fuel costs alone, the conversion pays for itself in 2 to 4 years and will conserve over 200,000 gallons of propane over the life of the system.

Section 7.

Conclusions

The photovoltaic hybrid power system at Dangling Rope Marina has been in service for over one year. In that time, this complex system has had few serious problems and demonstrated excellent availability. Site operators report satisfaction with the overall system performance and power quality.

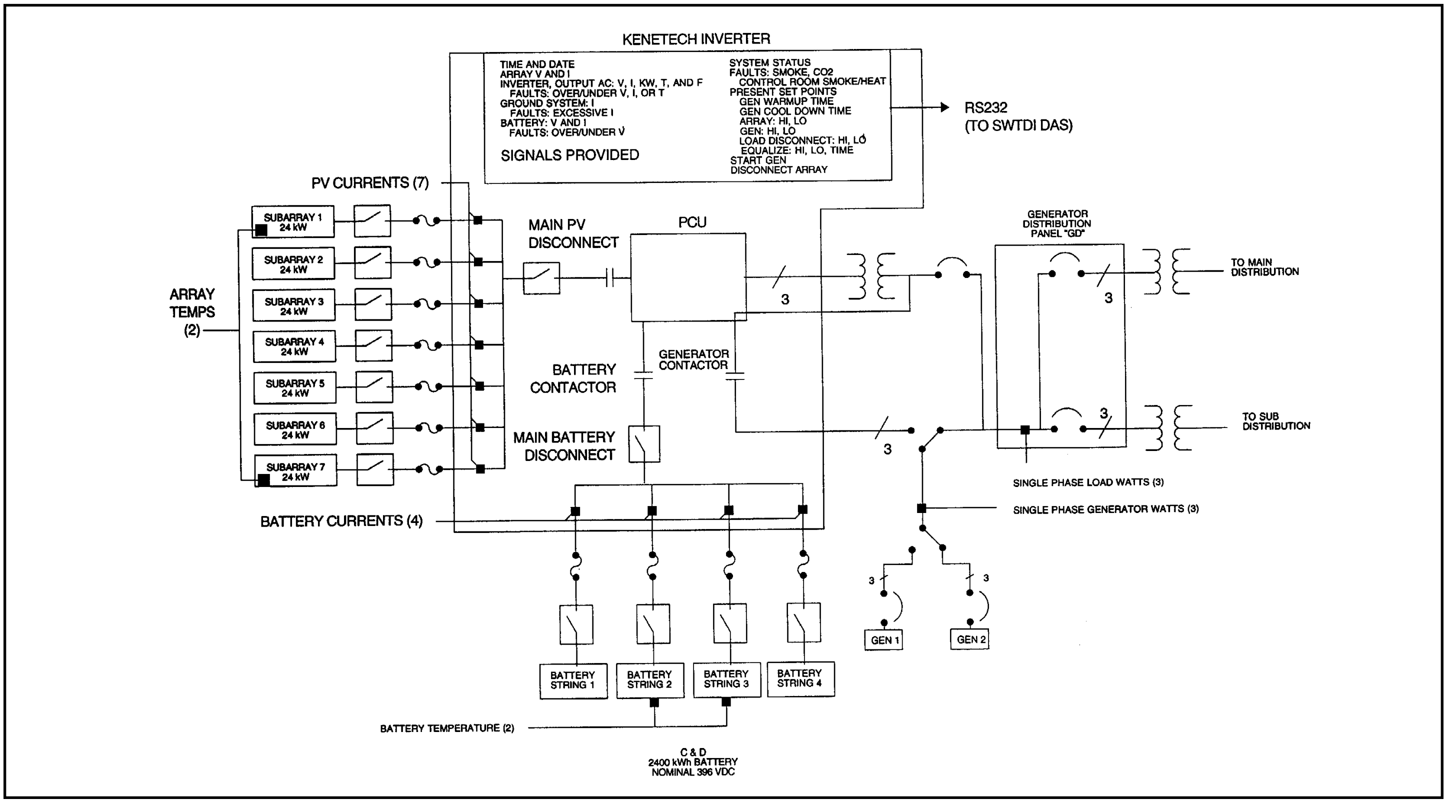
The few major problems experienced during the year were distributed among between three major subsystems: inverter, generators, battery. Overall, the system experienced 36 hours of downtime and was available for 99.6% of the time. Downtime records were not kept for the years prior to 1996. Interviews with long-time employees of the Marina's concessionaire indicate that reliability of power service has markedly improved since the hybrid system was installed.

The 1996/97 site electrical load was 438 MWh - larger than the 360 MWh load anticipated in 1992. Without implementation of an energy conservation incentive program for the site's concessionaire, site load will remain high. Site electrical load was met by photovoltaic (180.5 MWh) and propane generators (345.4 MWh). Total annual consumption of propane was 58,808 gallons: 54,442 by generators; 4366 by heaters and other appliances. Average cost of propane was $1.38 per gallon delivered by barge to the site.

Based on 1996/97 data, the net present value for 20-year operation of the photovoltaic hybrid is $2.89M. This compares with $2.71M for a diesel generator power system, and $2.98M for propane generator system. Thus, the hybrid is more expensive than full-time diesel generation and less expensive than full-time propane generation. Compared with a propane generator system, the hybrid achieves payback (i.e., becomes less expensive) in year 19 of operation.

Summary:

Though not the economic windfall anticipated in 1992, the system has been reliable and efficient. Compared with a full-time generator alternative, it requires less fuel, produces fewer emissions, is quieter, and requires less regular maintenance.



***Data Acquisition System.** The entire hybrid system is monitored by a dedicated data acquisition system that records system performance and weather data. It also exercises supervisory functions and control functions. This figure represents a one-line diagram of the photovoltaic hybrid system and indicates the parameters moni-*

Appendix A.

Generator Maintenance Schedule

The information in this appendix is copied from the Utah report and reflects costs for maintenance of a Caterpillar 3408 engine-generator set provided by ICM, a Caterpillar distributor in Salt Lake City, UT.

Based on field records, an additional $3,200/year was allocated for unscheduled and miscellaneous generator service for all systems using full-time generator operation.

Oil Change every 250 hours	
Oil (10 gal @ $4)	40
Oil filter (2 @ $17)	34
Gas filter ($13)	13
Air filter as needed ($15)	-------
Coolant pH check	-------
Labor (8 hrs @ $30)	240
250 hour maintenance	$327
Tune up every 5000 hours	
Replace injectors (4 @ $75)	300
Service alternator, starter, bearings	-------
Rebuild turbo	500
Labor (8 hrs @ $45.50)	364
Travel (8 hrs @ $38, $1/mile, 756 miles, hotel)	1,110
5000 hour maintenance	$2,274
Major overhaul every 10,000 hours	
Rebuild (4 @ $75)	14,000
Barge	2,000
Labor (32 hrs @ $30)	960
Labor (8 hrs @ $45.50)	364
Travel (8 hrs @ $38, $1/mile, 756 miles, hotel)	1,110
10,000 hour maintenance	$18,434
Engine replacement every 25,000 hours	
New engine-generator set	39,000
Barge	2,000
Labor (32 hrs @ $30)	960
Labor (8 hrs @ $45.50)	364
Travel (8 hrs @ $38, $1/mile, 756 miles, hotel)	1,110
25,000 hour maintenance	$43,434

Appendix B.

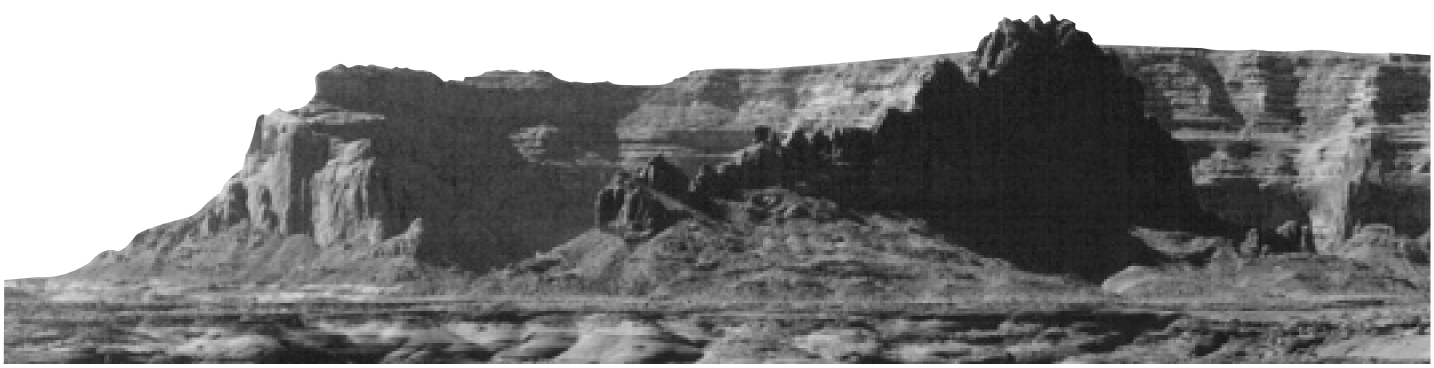
Parameters Used in LCC Calculations

The five power systems for which 20-year LCC were calculated are listed in Table B-1. The first two cases (Base92 and Hybrid92) are re-evaluations of the systems first assessed in the Utah report. The re-evaluation is provided so that these two cases and the three that follow are all calculated using the same methods and parameters. In all five cases, constant dollars are used with a discount rate of 4.1%.

Diesel fuel is always $1.58/gal and propane $1.38/gal delivered to the site. Fuel prices for both fuels are modified on a yearly basis by the fuel price escalation rates published by the Energy Information Administration of the Department of Energy.

The two 1992 cases assume an annual electrical load of 360 MWh which was the projected load for the site after the proposed fuel shifting and conservation measures were implemented. Also included in the analysis of the 1992 hybrid is the cost of 4000 gallons of propane for space heating, cooking, and water heating.

The 1996 cases all use the measured annual load of 438 MWh. The diesel-only base case is estimated to require 75,500 gallons of fuel to run the generators; the propane-only base case is estimated to require 110,305 gallons of fuel to run its generators. Both the diesel and propane-fueled base cases include an additional cost for 4366 gallons of propane needed for space heating, cooking, and water heating. This fuel is automatically included in the measured fuel usage of the 1996 hybrid system. The 1996 hybrid system case includes $2,400/year for scheduled battery service and testing.



Appendix C.

Discount Rate Sensitivity Analysis

In any economic analysis, a discount rate must be assumed based on current economic conditions and projections for future stability and growth. The figure 4.1% was used in the body of this paper to comply with the DOE guidelines for LCC calculations for federally funded 1996 energy projects. This appendix evaluates the sensitivity of the economic analyses to different discount rates. Specifically, the 20-year life cycle costs are recalculated for all three alternative systems using discount rates of 6% and 8%.

The hybrid system requires a large initial cost not incurred in either of the two generator-only alternatives. This makes the hybrid relatively insensitive to the discount rate which bears on future costs and has no affect on initial charges. Conversely, the two generator-only alternatives entail large recurring future costs and thus see their net present values greatly affected as the rate rises. In this case, raising the discount rate from 4.1% to 6%, decreases the net present value of each of the generator-only alternatives by 15% while the hybrid system decreases by only 9%. The 20-year LCC of the hybrid becomes more expensive than the propane-only alternative by $107k.

Increasing the projected discount rate to 8% continues the trend. The net present values of the generator-only alternatives drop an additional 14% compared with 8% for the hybrid system. The hybrid system becomes the most expensive system by $270k.

This analysis does not address any changes in the fuel price escalation rates for the these systems. An increase in these rates would favor the hybrid system which uses less fuel.

Table B-1

Dangling Rope Marina Photovoltaic Hybrid Power System
Five 20-Year LCC Cases

Case Number	Case Name	Description
1	Base92	360 MWh annual load; full-time diesel generator system.
2	Hybrid92	360 MWh annual load; 105 kW photovoltaic hybrid power system
3	Base96-d	438 MWh annual load; full-time diesel power system.
4	Base96-p	438 MWh annual load; full-time propane generator system.
5	Hybrid96	438 MWh annual load; 115 kW photovoltaic hybrid power system (the installed system)

Table C-1

Dangling Rope Marina
20 Year Life Cycle Cost Comparison
1996 System Alternatives with 6% Discount Rate

	Base96-d	Base96-p	Hybrid96
Initial Investment			
Capital Costs as of Service Date	$86,868	$86,868	$1,300,000
Future Costs Annual and Non -			
Annual Recurring Costs	$333,849	$333,849	$160,428
Energy-Related Costs	$1,746,301	$1,980,560	$1,015,712
Capital Replacements	$134,843	$134,843	$167,519
Net Present Value	$2,301,860	$2,536,120	$2,643,658

Table C-2

Dangling Rope Marina
20 Year Life Cycle Cost Comparison
1996 System Alternatives with 8% Discount Rate

	Base96-d	Base96-p	Hybrid96
Initial Investment			
Capital Costs as of Service Date	$86,868	$86,868	$1,300,000
Future Costs			
Annual and Non-Annual Recurring Costs	$284,472	$284,472	$135,674
Energy-Related Costs	$1,483,028	$1,687,717	$865,531
Capital Replacements	$110,977	$110,977	$138,958
Net Present Value	$1,965,345	$2,170,034	$2,440,162

BRIEFS

1998 Photovoltaic Performance and Reliability Workshop

The National Center for Photovoltaics (Sandia National Laboratories and the National Renewable Energy Laboratory) will again this year host a Photovoltaic Performance and Reliability Workshop. Site-host of this year's two-day workshop will be the Florida Solar Energy Center, University of Central Florida, and the workshop itself will be headquartered at the Howard Johnson Plaza Hotel, soon to be Doubletree, Cocoa Beach, Florida. The workshop is set for November 3-4.

The workshop will focus on reliability and maintenance issues that add to the overall cost of photovoltaic systems, and should be of interest to a broad spectrum of the photovoltaic community. An important goal of the workshop will be to agree on strategies to enhance performance through improved hardware, improved system designs, and improved maintenance strategies.

Conference rates are $75 to $95, and registrants may choose either the Howard Johnson Express Courtyard or the adjoining Doubletree Tower. Call (407) 783-9222 to make your room reservations. Be sure to request the "Photovoltaic Performance and Reliability Workshop" room rates. Formal workshop registration forms and other information will be provided at a later date. Ben Kroposki, National Renewable Energy Laboratory, and Mike Thomas, Sandia National Laboratories, are 1998 workshop co-chairs.

Please visit Sandia's website:

www.sandia.gov/pv

New material has been added, notably updated Balance of System information. If you would like to be notified as updates occur on this website, take advantage of the new response form on the homepage. Some of our listings include

- Photovoltaic components
- Balance of system
- System design
- Projects — lists of projects and success stories
- System operation
- Library: glossary and on-line publications
- Photovoltaics quarterly highlights and announcements
- Answers to frequently asked questions about photovoltaics
- Feedback page — a way to communicate with Sandia's Photovoltaics staff
- A search function

Sandia creates and distributes a variety of publications on photovoltaic systems and their applications. For a list of these documents, please contact the Photovoltaic Systems Assistance Center:

through e-mail: ***pvsac@sandia.gov***

by phone: ***505-844-3698***

by FAX: ***505-844-6541***

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Forward and address correction requested

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